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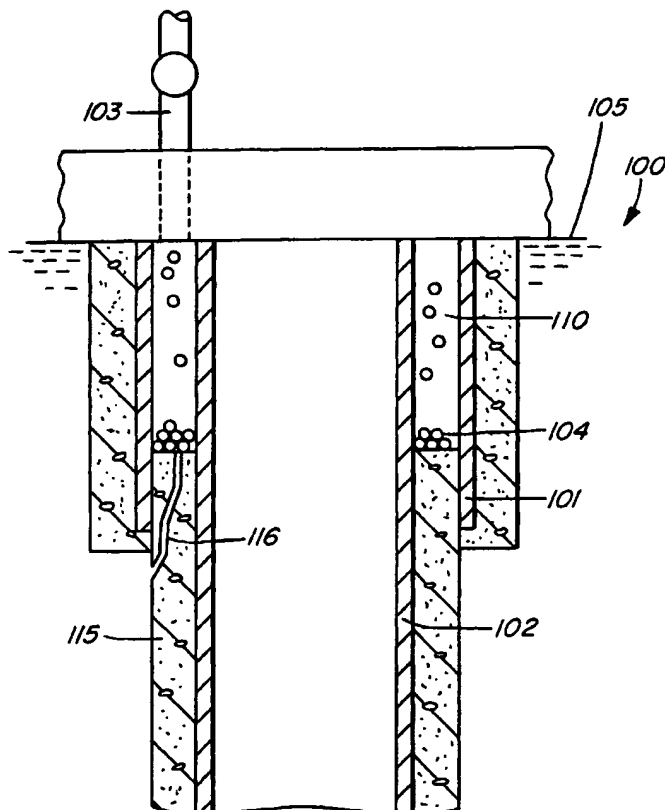
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[Continued on next page]

(54) Title: ANNULUS SEALING METHOD USING EUTECTIC METAL AND HEAT INDUCTION



(57) Abstract: Apparatus and method for melting metal in the annulus of an oil or gas well and thereby sealing the annulus to prevent shallow gas leakage and the like. Conveniently, eutectic metal is positioned within the annulus between the production and surface casing of the well and above the well cement. An electrical inductive tool is lowered into position and used to provide the necessary heat to melt the metal. The electrical inductive tool may be removed following the sealing of the annulus. Radioactive tracers may be used with the eutectic metal to confirm the desired location for the melt to occur.

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*For two-letter codes and other abbreviations, refer to the "Guidance Notes on Codes and Abbreviations" appearing at the beginning of each regular issue of the PCT Gazette.*

**TITLE**

ANNULUS SEALING METHOD USING EUTECTIC METAL AND HEAT INDUCTION

**INTRODUCTION**

This invention relates to a method and apparatus for melting metals and, more particularly, for melting eutectic metals which metals may be used to seal the annulus between the production and surface casing in oil and gas wells.

**BACKGROUND OF THE INVENTION**

The leakage of shallow gas through the casing cement used in well completion is often a problem in oil and gas wells. Such leakage is generally caused by inherent high pressures in oil and gas wells and can create environmental problems and compromise well safety. This leakage most often occurs because of cracks or other imperfections that occur in the cement that is injected into the well during well completion procedures between

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the surface and production casings.

Techniques for preventing shallow gas leakage are disclosed in Rusch, David W. et al, "Use of Pressure Activated Sealants to Cure Sources of Casing Pressure", SPE (Society of Petroleum Engineers) Paper 55996. These techniques use the application of an epoxy sealing technique. One disadvantage in using the technique taught by Rusch et al is that high pressure differentials across the source of leakage are required.

There is disclosed and illustrated a method and apparatus for subterranean thermal conditioning of petroleum in oil wells in Canadian patent application 2,208,197 (Isted) which application was laid open in Canada on or about December 18, 1998. This document teaches the use of an electrical induction technique to provide heat to oil, particularly high viscosity heavy oil and oil containing high proportions of wax. Electrical induction is thought to be a much preferred method to supply heat to oil within a well because of the combustibility of the hydrocarbon products. Further, the benefits of this technique over the previous steam application technique include the fact that the steam used may cause damage to the permeability of the reservoir. This change may adversely affect oil production.

The use of electrical induction by Isted which is disclosed in the above-identified '197 application, however, is not contemplated to be also useful for

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sealing an annular space between surface and production casing.

#### SUMMARY OF THE INVENTION

According to one aspect of the invention, there is provided a method for melting metal in an annulus between the surface and production casing of an oil or gas well, said method comprising positioning metal at a predetermined location in said annulus, applying heat to said metal by electrical induction, melting said metal by said application of electrical induction heat and terminating said application of heat following said melting of said metal thereby to allow said metal to solidify within said annulus.

According to a further aspect of the invention, there is provided apparatus for melting metal in an annulus between the production and surface casing of an oil or gas well, said apparatus comprising an opening to position said metal at a predetermined location within said annulus, an electrical induction apparatus to apply heat to said metal at said predetermined location and to melt said metal within said annulus and a switch to initiate and terminate said application of said heat by said electrical induction apparatus.

#### BRIEF DESCRIPTION OF THE SEVERAL VIEWS OF THE DRAWINGS

Specific embodiments of the invention will now be described, by way of example only, with the use of

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drawings in which:

Figure 1 is diagrammatic cross-sectional view of an oil or gas well particularly illustrating the location of the eutectic metal and the induction apparatus according to one aspect of the invention;

Figure 2 is an enlarged diagrammatic cross-sectional view of an oil or gas well particularly illustrating the cement used in setting the production and surface casings relative to the metal used for sealing the annulus;

Figure 3 is a diagrammatic side cross-sectional view of a magnetic induction assembly positioned in a vertical well and being in accordance with the present invention;

Figure 4 is a diagrammatic side cross-sectional view of one of the magnetic induction apparatuses from the magnetic induction assembly illustrated in Figure 3;

Figure 5 is a diagrammatic plan cross-sectional view, taken along section lines V-V of the magnetic induction apparatus illustrated in Figure 4;

Figure 6 is a diagrammatic side, cross-sectional view of the primary electrical connection from the magnetic induction assembly illustrated in Figures 3 and 4;

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Figure 7 is a diagrammatic end cross-sectional view, taken along section lines VI-VI of the primary electrical connection illustrated in Figure 6;

Figure 8 is a diagrammatic partial side cross-sectional view of the male portion of the conductive coupling from the magnetic induction assembly illustrated in Figure 3;

Figure 9 is an end elevation view of the male portion of the conductive coupling illustrated in Figure 8 taken along IX-IX of Figure 8;

Figure 10 is a side elevation sectional view of a portion of the male portion of the conductive coupling illustrated in Figure 8;

Figure 11 is a side sectional view of a female portion of the conductive coupling of the magnetic induction assembly illustrated in Figure 3;

Figure 12 is a side sectional view of the male portion illustrated in Figure 8, coupled with the female portion illustrated in Figure 11;

Figure 13 is a side sectional view of the adapter sub of the magnetic induction assembly illustrated in Figure 3;

Figure 14 is an end sectional view taken along lines XIV-XIV of Figure 13;

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Figure 15 is a schematic of a power control unit used with the magnetic induction assembly according to the invention;

Figure 16, appearing with Figure 14, is an end sectional view of a first alternative internal configuration for the magnetic induction apparatus according to the invention;

Figure 17 is an end sectional elevation view of a second alternative internal configuration for the magnetic induction apparatus according to the invention;

Figure 18 is an end sectional view of a third alternative internal configuration for the magnetic induction apparatus according to the invention;

Figure 19 is a diagrammatic side elevation sectional view of the instrument and sensor components used with the magnetic induction assembly according to the invention; and

Figure 20 is an end elevation sectional view of a production tubing heater illustrated in Figure 3.

#### DESCRIPTION OF SPECIFIC EMBODIMENT

Referring now to the drawings, the surface and production casings of an oil or gas well generally illustrated at 100 are illustrated at 101, 102, respectively. The outside or surface casing 101 extends



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from the surface 105 (Figure 2) of the formation downwardly and the production casing 102 extends downwardly within the surface casing 101. An annulus 110 is formed between the production and surface casings 101, 102, respectively. It will be appreciated that Figure 2 is intended to diagrammatically illustrate an offshore well while Figure 3 is intended to diagrammatically illustrate an onshore oil or gas well.

An injection port 103 extends downwardly from the surface into the annulus 110 between the surface and production casings 101, 102. The injection port 103 is used not only to inject certain fluids into the annulus 110 but is also used to carry small shot pellets 104 in the form of BB's which are poured into place via the injection port 103. The small shot pellets 104 are preferably made from an eutectic metal; that is, they have a relatively low melting point and can be liquified by the application of certain heat as will be explained. The injection port 103 further and conveniently may carry a suitable marker or tracer material such as radioactive boron or the like which is added to the shot 104 so that the location of the eutectic metal in the annulus 110 can be detected with standard well logging tools to ensure proper quantities of the metal being appropriate situated.

An electrical induction apparatus generally illustrated at 111 is located within the production casing 102. It may conveniently comprise three inductive elements 112, 113, 114 which are mounted on a wire line

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120 which is used to raise or lower the induction apparatus 111 so as to appropriately locate it within the production casing 102 adjacent the shot pellets 104 following their placement.

The induction apparatus 111 will be described in greater detail.

More than one magnetic induction apparatus 111 (Figure 3) may be used and they may be joined together as part of a magnetic induction assembly, generally indicated at 126. A magnetic field is induced in and adjacent to well casing 102 by means of the magnetic induction apparatus 111 thereby producing heat.

The magnetic induction assembly 126 includes an adapter sub 128, a electrical feed through assembly 130, and a plurality of magnetic induction apparatus 111 joined by conductive couplings 132.

Each magnetic induction apparatus 111 has a tubular housing 134 (Figures 4 and 5). Housing 134 may be magnetic or non-magnetic depending upon whether it is desirable to build up heat in the housing itself. Housing 134 has external centralizer members 136 (Figure 6) and a magnetically permeable core 138 is disposed in housing 134. Electrical conductors 140 are wound in close proximity to core insulated dividers 142 which are used for electrically isolating the electrical conductors 140. Housing 134 has may be filled with an insulating liquid, which may be transformed to a substantially

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incompressible gel 137 so as to form a permanent electrical insulation and provide a filling that will increase the resistance of housing 134 to the high external pressures inherent in the well 100. The cross sectional area of magnetic core 138, the number of turns of conductors 140, and the current originating from the power control unit (PCU) may be selected to release the desired amount of heat when stimulated with a fluctuating magnetic field at a frequency such that no substantial net mechanical movement is created by the electromagnetic waves. Power conducting wires 141 and signal conducting wires 143 are used to facilitate connection with the PCU. For reduced heat release, a lower frequency, fewer turns of conductor, lower current, or less cross sectional area or a combination will lower the heat release per unit of length. Sections of inductor constructed in this fashion allow the same current to pass from one magnetic inductor apparatus 111 to another.

Figures 16, 17 and 18 illustrate alternative internal configurations for electrical conductors 140 and core 138 but are not intended to limit the various configurations possible. Where close fitting of inductor poles to the casing or liner is practical, additional magnetic poles may be added to the configuration with single or multiple phase wiring through each to suit the requirements. A number of inductors (i.e., core 138 with electrical conductors 140) may be contained in housing 134 with an overall length to suit the requirements and or shipping restraints. A multiplicity of housings 134 may connect several magnetic induction apparatuses 111 together to form a magnetic induction assembly 126.

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These induction apparatuses 111 may be connected with flanged and bolted joints or with threaded ends similar in configuration and form to those used in the petroleum industry for completion of oil and gas wells. At each connection for magnetic induction apparatus 111, there is positioned a conductive coupling 132. Conductive coupling 132 may consist of various mechanical connectors and flexible lead wires.

The adapter sub 128 (Figure 13) allows a cable, conveniently electrical submersible pump (ESP) cable 166, to be fed into top 168 of magnetic induction assembly 126 although other types of cables are available. Adapter sub 128 comprises a length of tubing 170 which has an enlarged section 174 near the midpoint such that the ESP cable 166 may pass through tubing 170 and transition to outer face 172 of tubing 70 by passing through a passageway 76 in enlarged section 174. Adapter sub 128 has a threaded coupling 178 to which the wellbore tubulars (not shown) may be attached thereby suspending magnetic induction assembly 126 at the desired location and allowing retrieval of the magnetic induction assembly 126 by withdrawing the wellbore tubulars.

ESP cable 166 is coupled to an uppermost end 168 of magnetic induction assembly 126 by means of electrical feed through assembly 130 (Figure 6). These assemblies are specifically designed for connecting cable to cable, cable through a wellhead, and cable to equipment and the like. The connection may also be made through a fabricated pack-off comprised of a multiplicity

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of insulated conductors with gasket packing compressed in a gland around the conductors so as to seal formation fluids from entering the inductor container. Electrical feed through assembly 130 has the advantage that normal oil field thread make-up procedures may be employed thus facilitating installation and retrieval. Use of a standard power feed allows standard oil field cable splicing practice to be followed when connecting to the ESP cable from magnetic induction assembly 126 to surface.

Magnetic induction assembly 126 works in conjunction with a power conditioning unit (PCU) 180 located at the surface or other desired location (Figure 3). PCU 180 utilizes single and multiphase electrical energy either as supplied from electrical systems or portable generators to provide modified output waves for magnetic induction assembly 126. The output wave selected is dependent upon the intended application but square wave forms have been found to be most beneficial in producing heat. Maximum inductive heating is realized from waves having rapid current changes (at a given frequency) such that the generation of square or sharp crested waves are desirable for heating purposes. The PCU 180 has a computer processor 181 (Figure 15). It is preferred that PCU 180 includes a solid state wave generating device such as silicon controlled rectifier(SCR) or insulated gate bipolar transistor(IGBT) 121 controlled from an interactive computer based control system in order to match system and load requirements. One form of PCU 180 may be configured with a multi tap

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transformer, SCR or IGBT and current limit sensing on-off controls. The preferred system consists of an incoming breaker, overloads, contactors, followed by a multitap power transformer, an IGBT or SCR bridge network and micro-processor based control system to charge capacitors to a suitable voltage given the variable load demands. The output wave should then be generated by a micro-controller. The micro-controller can be programmed or provided with application specific integrated circuits, in conjunction with interactive control of IGBT and SCR, control the output electrical wave so as to enhance the heating action. Operating controls for each phase include antishoot through controls such that false triggering and over current conditions are avoided and output wave parameters are generated to create the in situ heating as required. Incorporated within the operating and control system is a data storage function to record both operating mode and response so that optimization of the operating mode may be made either under automatic or manual control. PCU 180 includes a supply breaker 182, overloads 184, multiple contactors 186 (or alternatively a multiplicity of thyristors or insulated gate bipolar transistors), a multitap power transformer 188, a three phase IGBT or comparable semiconductor bridge 190, a multiplicity of power capacitors 192, IGBT 121 output semiconductor anti shoot through current sensors 194, together with current and voltage sensors 196. PCU 180 delivers single and multiphase variable frequency electrical output waves for the purpose of heating, individual unidirectional output wave, to one or more of magnetic induction apparatuses

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111, such that the high current in rush of a DC supply can be avoided. PCU 180 is equipped to receive the downhole instrument signals interpret the signals and control operation in accordance with program arid set points. PCU 180 is connected to the well head with ESP cable 166, which may also carry the information signals (Figure 3). An instrument device 198 is located within each magnetic induction apparatus 111 (Figure 19) for the purpose of receiving AC electrical energy from the inductor supply, so as to charge a battery 200, and which, on signal from PCU 180, commences to sense, in a sequential manner, the electrical values of a multiplicity of transducers 202 located at selected positions along magnetic induction apparatus 111 such that temperatures and pressures and such other signals as may be connected at those locations may be sensed and as part of the same sequence. One or more pressure transducers may be sensed to indicate pressure at selected locations and the instrument outputs a sequential series of signals which travel on the power supply wire(s) to the PCU wherein the signal is received and interpreted. Such information may then be used to provide operational control and adjust the output and wave shape to affect the desired output in accordance with control programs contained within the PCU computer and micro controllers.

#### OPERATION

In operation and with initial reference to Figures 1 and 2, the eutectic metal, conveniently solder

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and being in the form of BB's or shot 104, is inserted into the annulus 110 by way of injection port line 103 which has allows installation of the shot 104 to a desired position within the annulus 110. The solder shot 104 is inserted into the annulus 110 to such an extent that the annulus is filled with the shot 104 for a predetermined distance above the well cement 115 as best illustrated in Figure 2. Radioactive tracer elements can conveniently be added to the shot 104 thereby allowing standard well logging equipment to determine whether the correct location of the shot 104 has been reached and whether it is of consistent thickness or depth around the annulus 110.

Thereafter, the electrical induction heating apparatus 111 is lowered into position within the production casing and its operation is initiated (Figure 1) as heretofore described. The heat generated by the induction apparatus 111 is transmitted through the production casing 102 to the shot 104 and melts the eutectic metal 104. This timing period can be calculated so that the required melting time period is reached and the temperature of the production casing to obtain such melting can be determined.

Following the melting of the shot 104 and, therefore, the sealing of the annulus 110 above the cement 115 between the surface and production casings 101, 102, the operation of the electrical induction apparatus 111 is terminated and the apparatus 111 is removed from the production casing 102. Any leakage



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through anomalies 116 in the cement 115 is intended to be terminated by the now solid eutectic metal 104. Of course, additional metal may be added if desired or required. The use of the induction apparatus 111 to generate heat reduces the inherent risk due to the presence of combustible hydrocarbons.

A eutectic metal mixture, such as tin-lead solder 104, is used because the melting and freezing points of the mixture is lower than that of either pure metal in the mixture and, therefore, melting and subsequent solidification of the mixture may be obtained as desired with the operation of the induction apparatus 111 being initiated and terminated appropriately. This mixture also bonds well with the metal of the production and surface casings 102, 101. The addition of bismuth to the mixture can improve the bonding action. Other additions may have the same effect. Other metals or mixtures may well be used for different applications depending upon the specific use desired.

Many additional modifications will readily occur to those skilled in the art to which the invention relates and the specific embodiments described should be taken as illustrative of the invention only and not as limiting its scope as defined in accordance with the accompanying claims.

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I CLAIM:

1. Method for melting metal in an annulus between the surface and production casing of an oil or gas well, said method comprising positioning said metal at a predetermined location in said annulus, applying heat to said metal by electrical induction, melting said metal by said application of electrical induction heat and terminating said application of heat following said melting of said metal thereby to allow said metal to solidify within said annulus.

2. Method as in claim 1 wherein said metal is a eutectic metal.

3. Method as in claim 2 wherein said eutectic metal is a lead-tin solder mixture.

4. Method as in claim 3 and further comprising adding bismuth to said mixture.

5. Method for melting eutectic metal as in claim 2 and further comprising inserting said eutectic metal with through an injection port into said annulus.

6. Method as in claim 2 wherein said predetermined location is determined by adding tracer elements to said eutectic metal and obtaining the position of said tracer elements in said annulus.

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7. Apparatus for melting metal in an annulus between the production and surface casing of an oil or gas well, said apparatus comprising an opening to position said metal at a predetermined location within said annulus, an electrical induction apparatus to apply heat to said metal at said predetermined location and to melt said eutectic metal within said annulus and a switch to initiate and terminate said application of said heat by said electrical induction apparatus.

8. Apparatus as in claim 7 wherein said metal is a eutectic metal.

9. Apparatus as in claim 8 wherein said eutectic metal is a lead-tin mixture.

10. Apparatus as in claim 9 and further including bismuth in said lead-tin mixture.

11. Apparatus as in claim 9 and further comprising a feed line extending from said opening to said annulus.

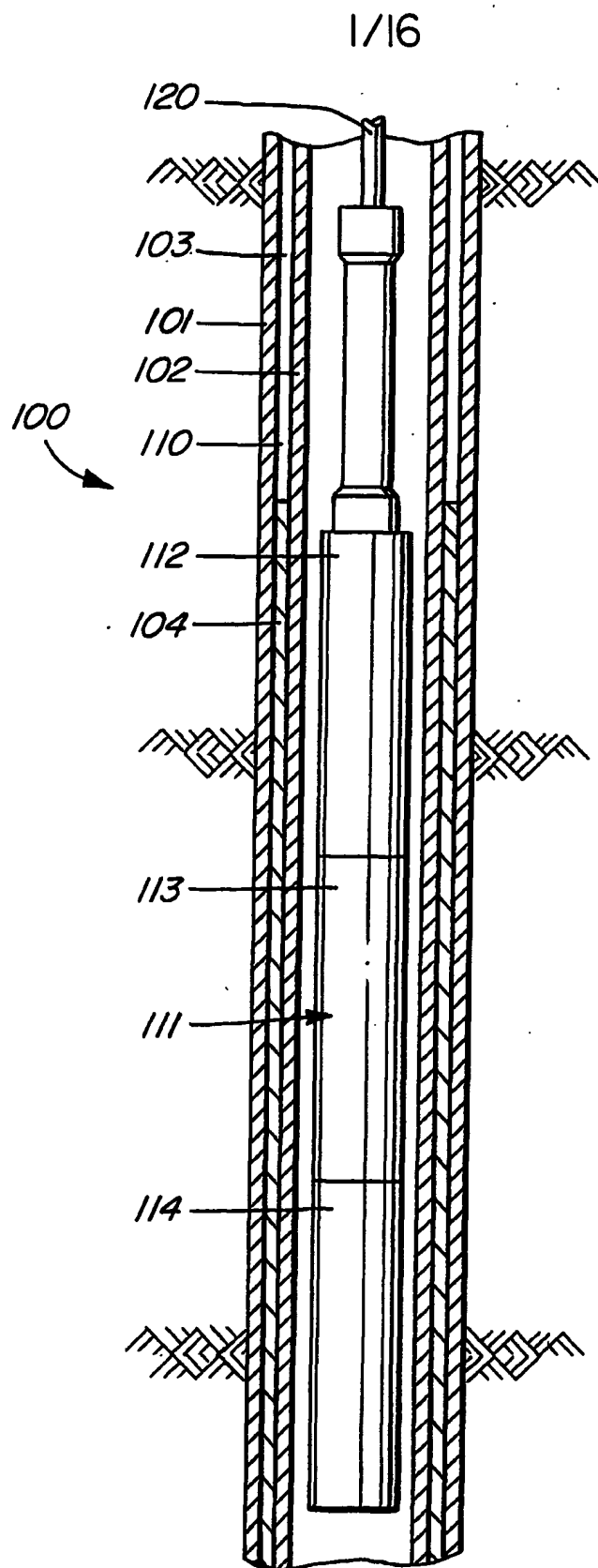
12. Apparatus as in claim 8 and further comprising tracer elements added to said eutectic metal.

13. Apparatus as in claim 12 wherein said tracer elements are radioactive.

14. Apparatus as in claim 7 and further comprising a sensor to determine the position of said

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tracer elements in said annulus.

**FIG. I**

SUBSTITUTE SHEET (RULE 26)

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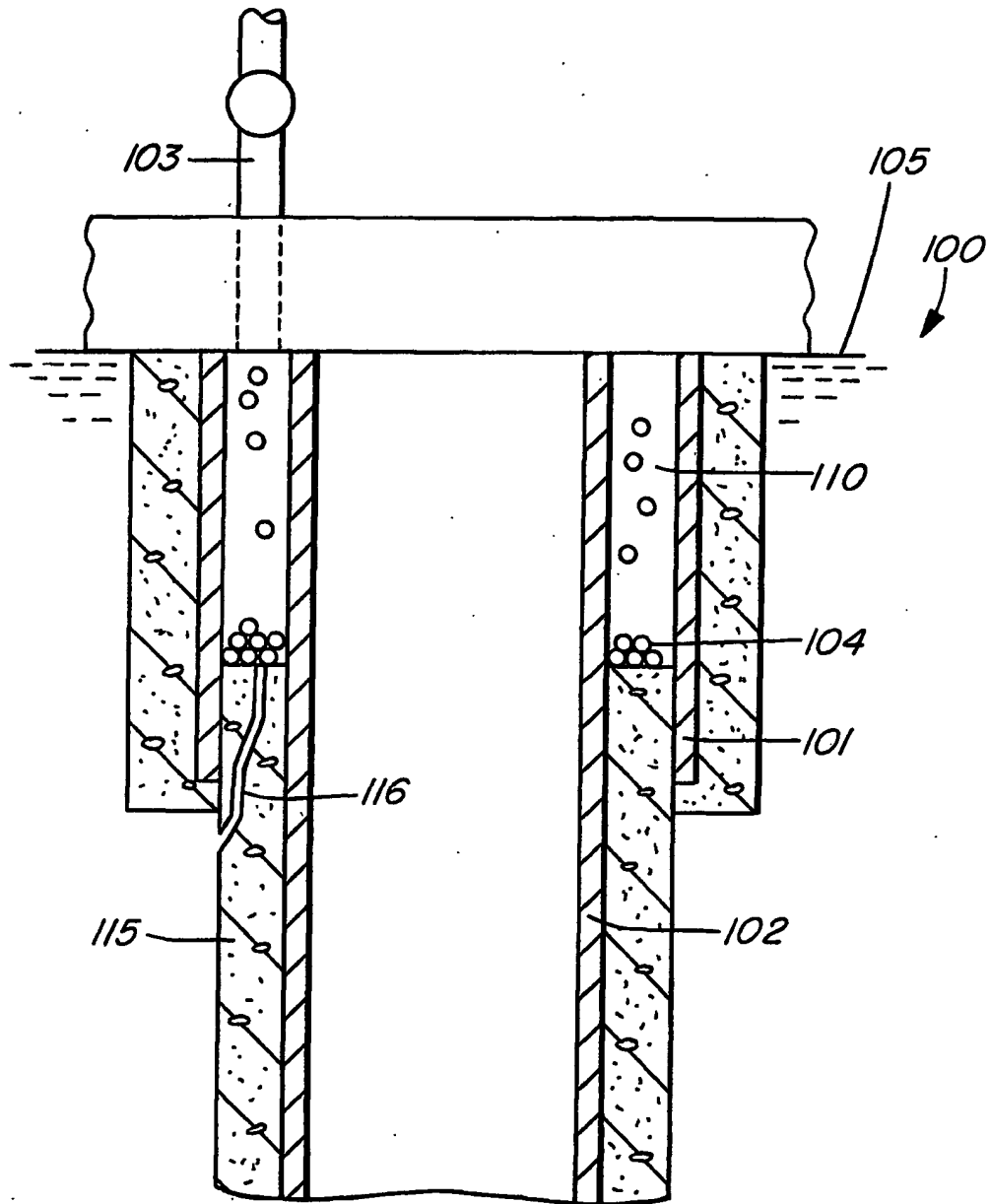


FIG. 2

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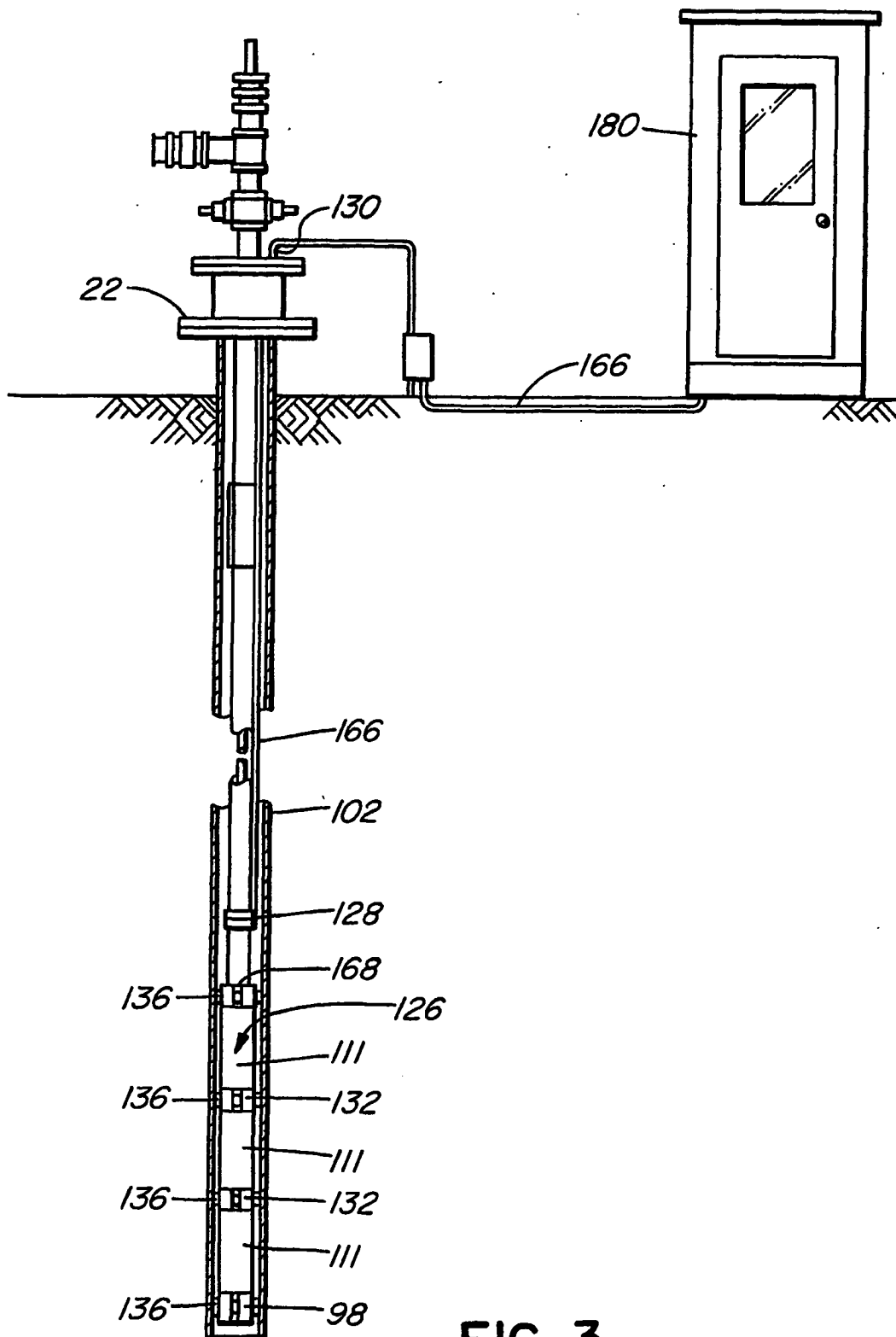


FIG. 3

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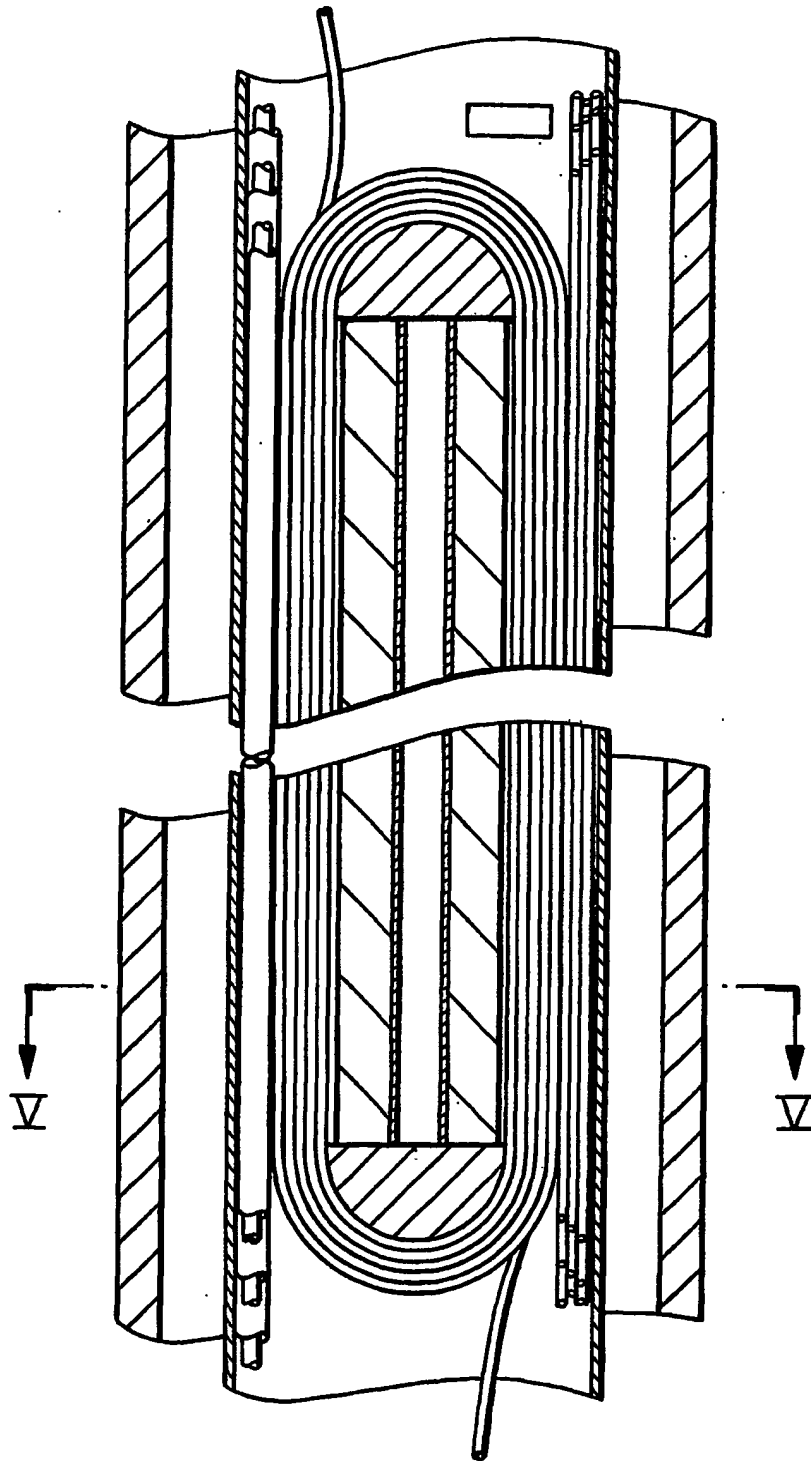


FIG. 4



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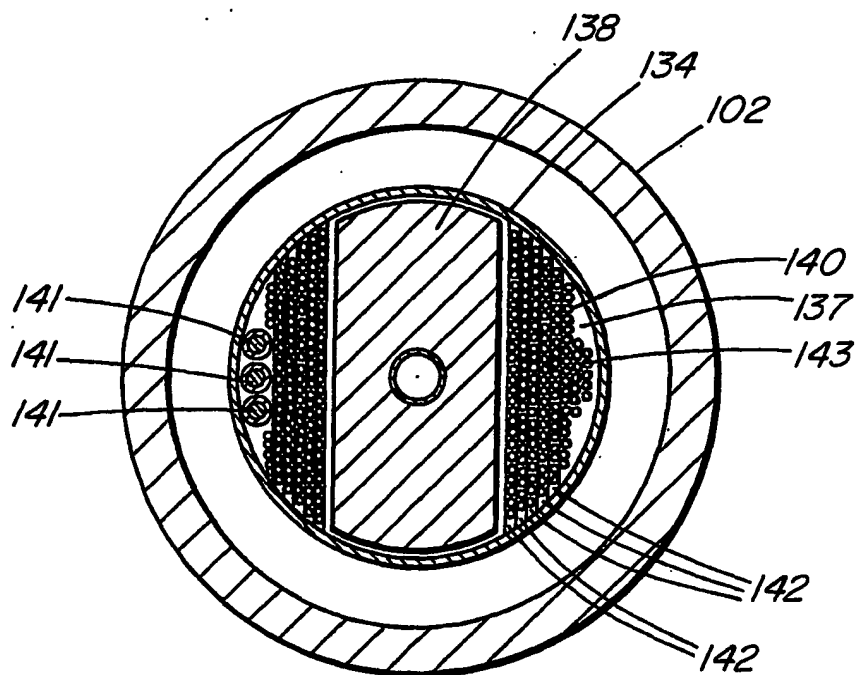


FIG. 5

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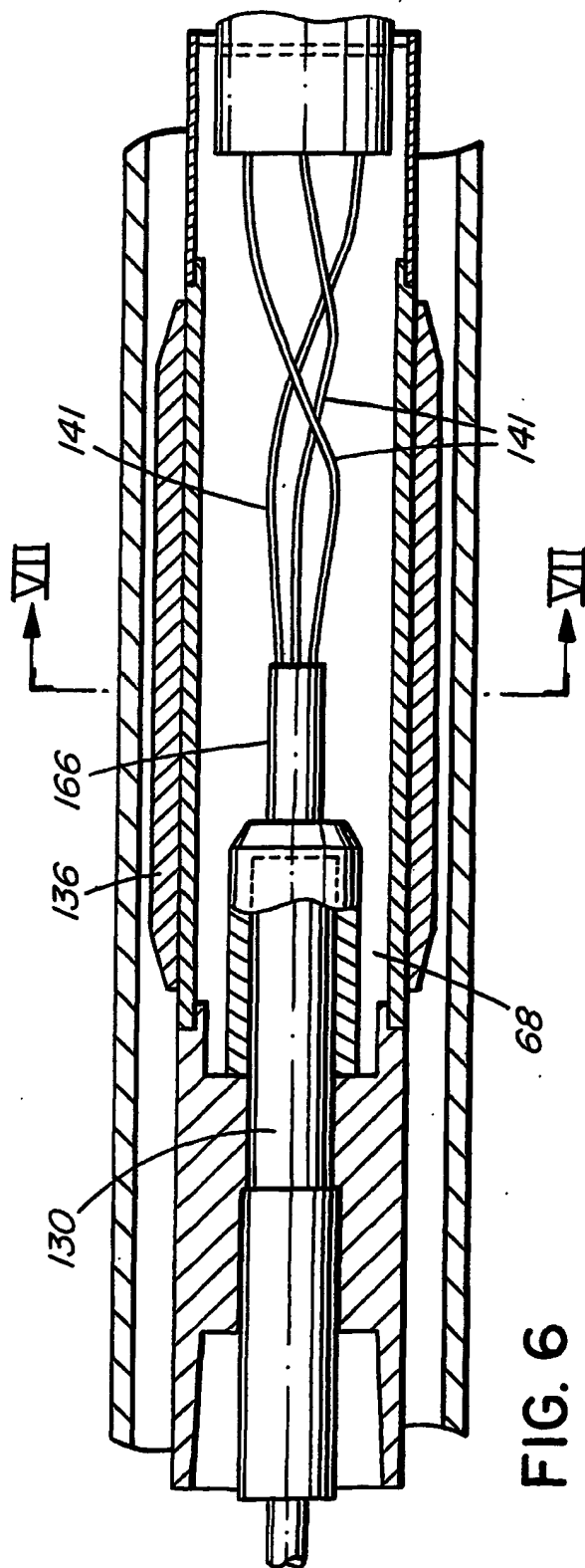


FIG. 6

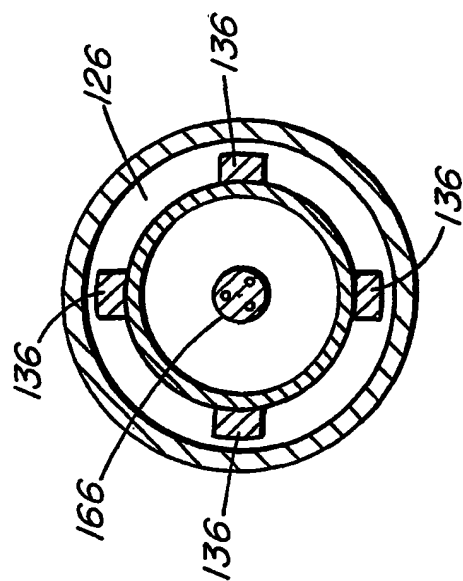


FIG. 7

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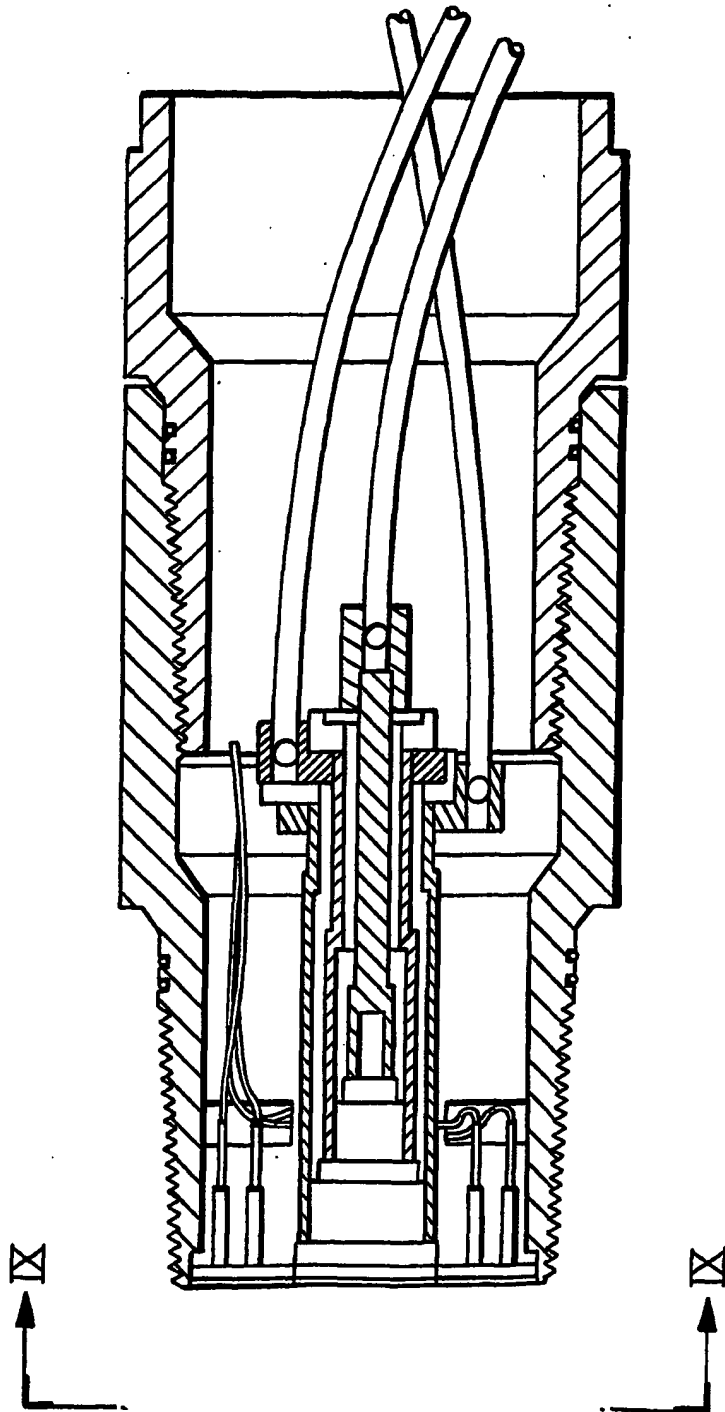


FIG. 8

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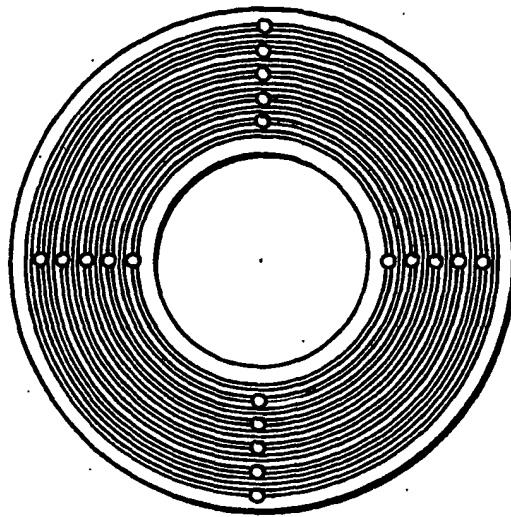


FIG. 9

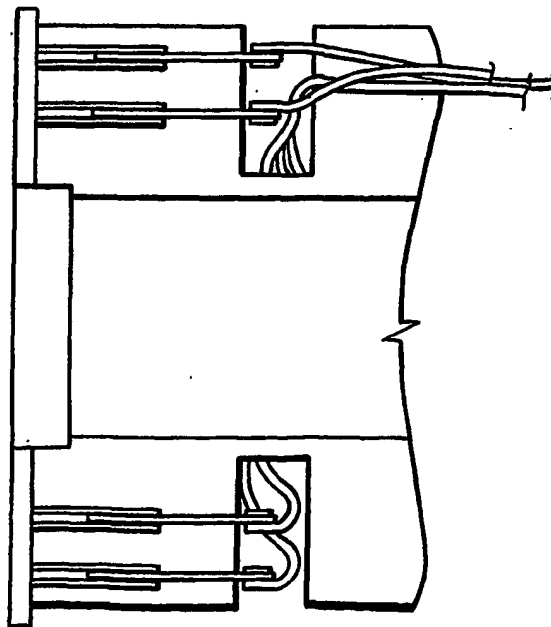


FIG. 10

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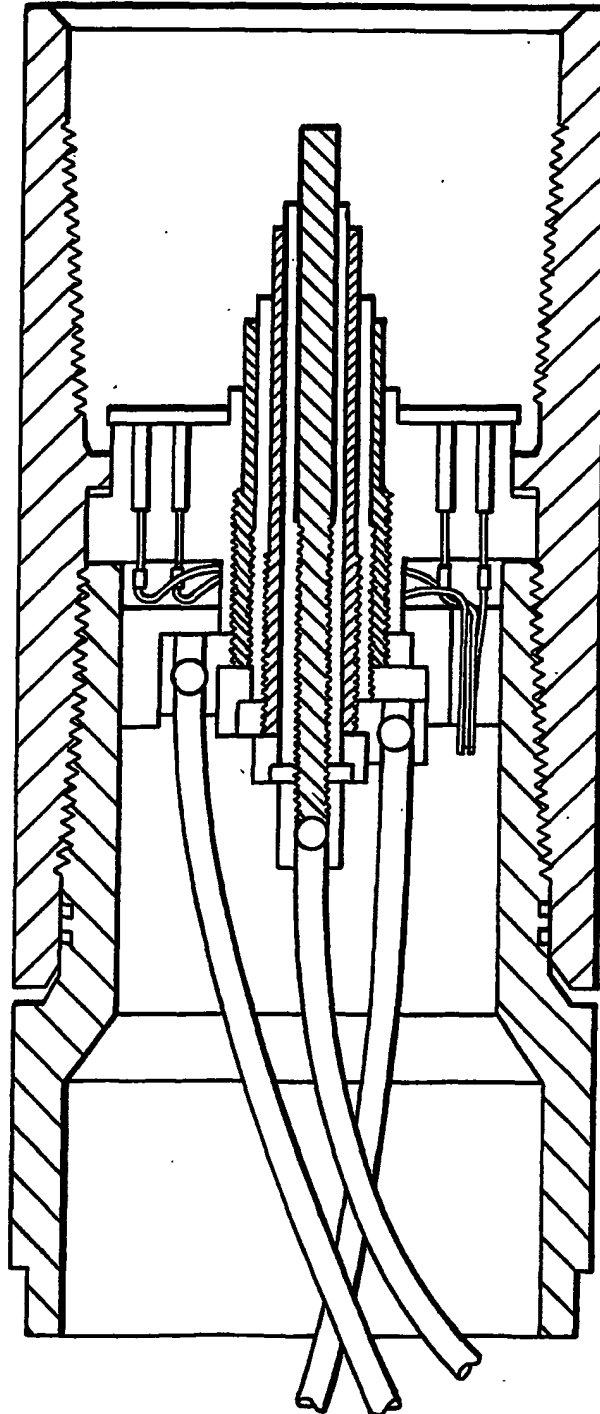


FIG. 11

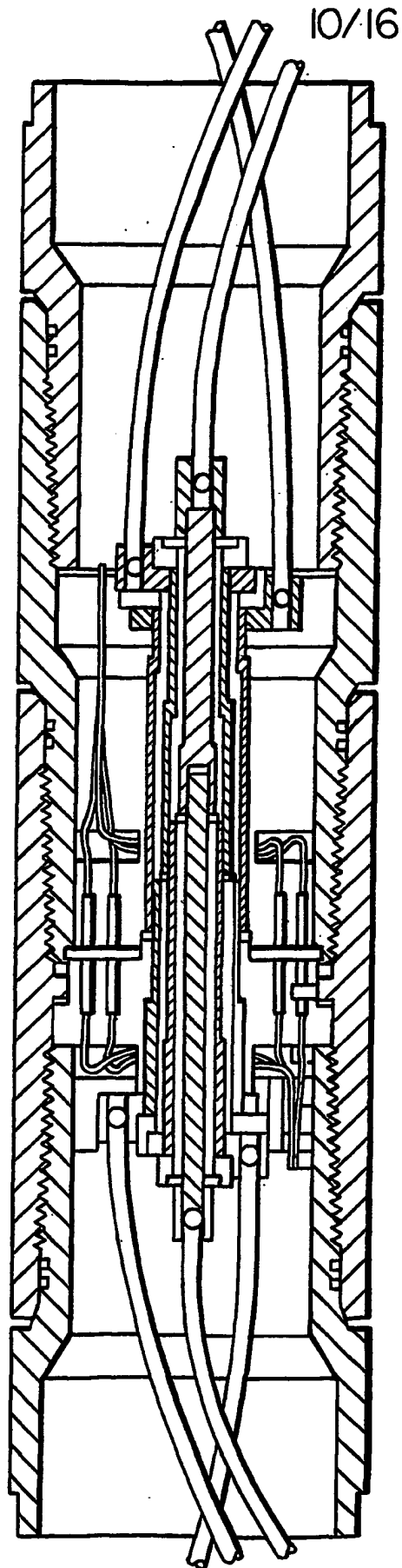


FIG. 12

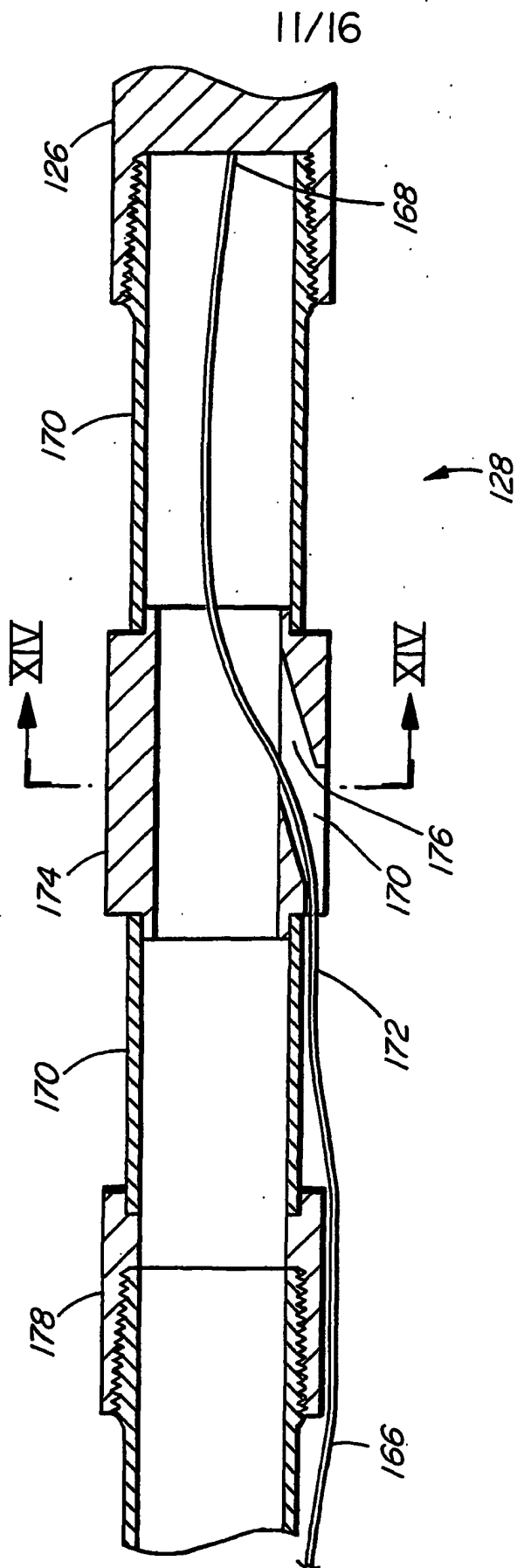


FIG. 13

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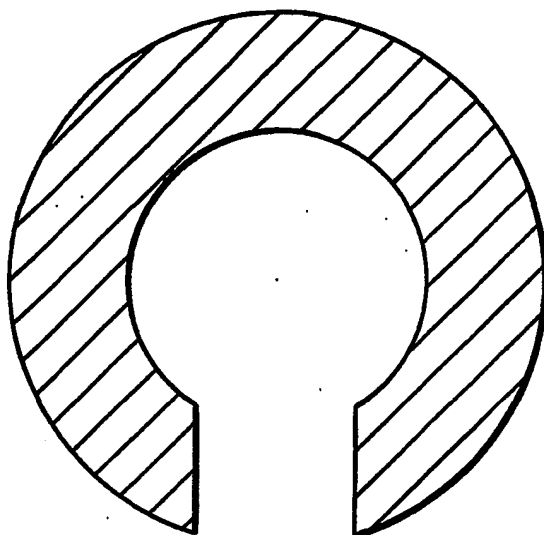


FIG. 14

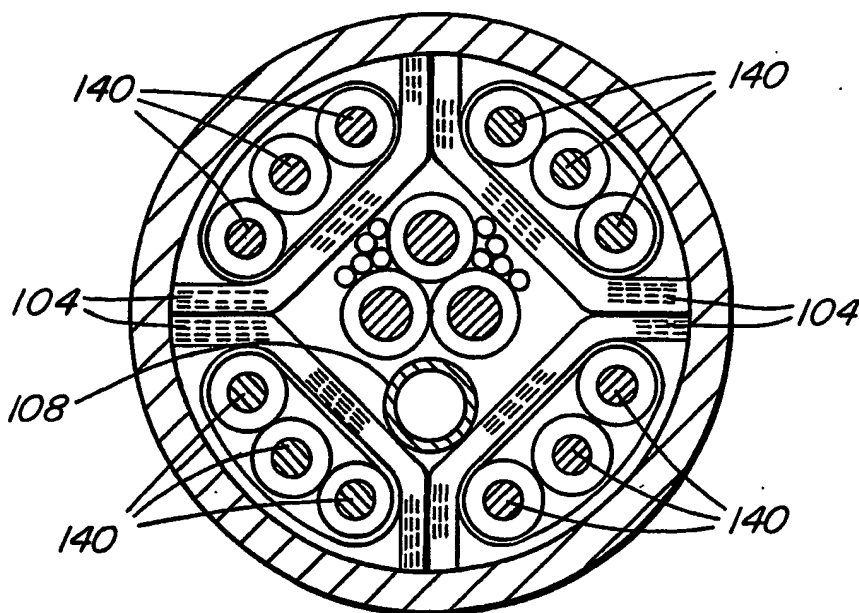


FIG. 16



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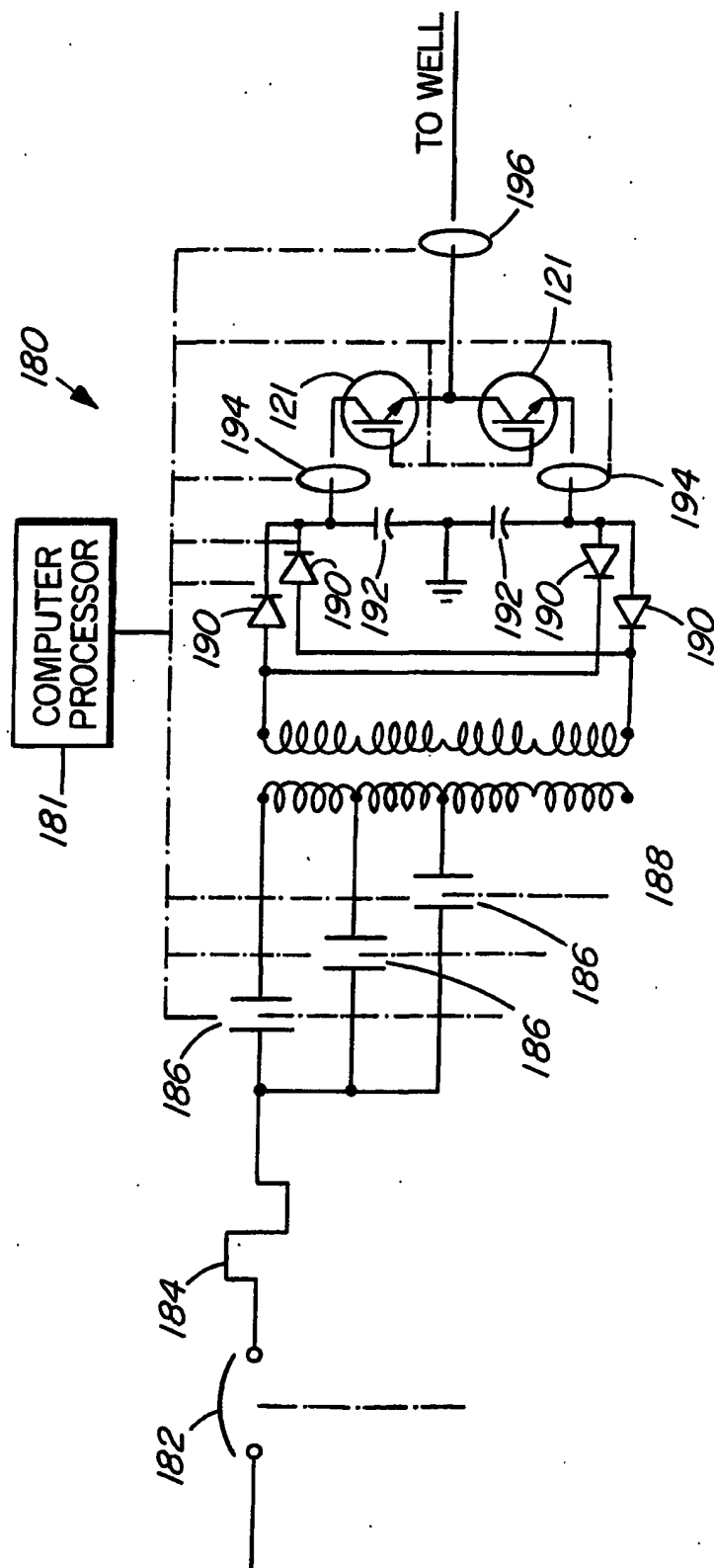


FIG. 15

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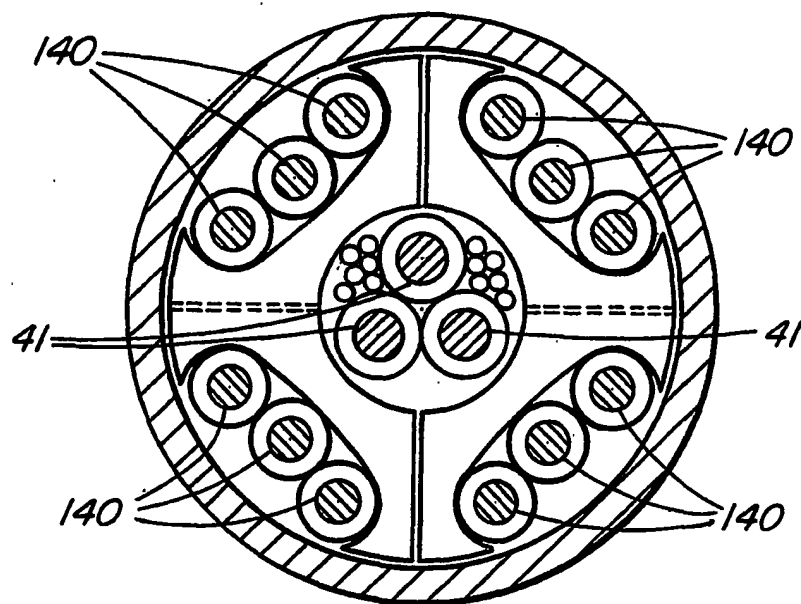


FIG. 17

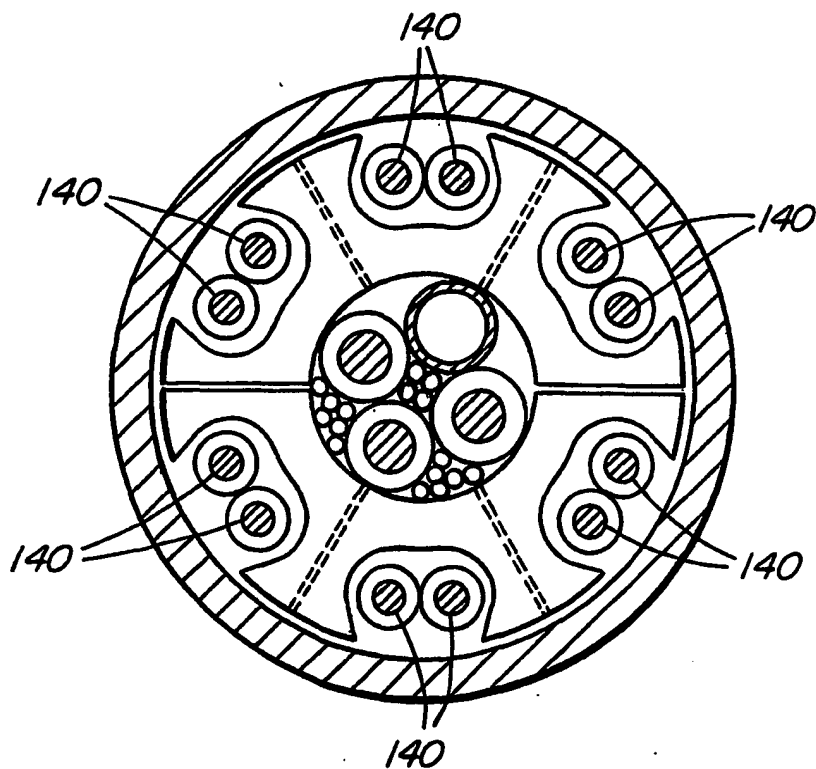


FIG. 18

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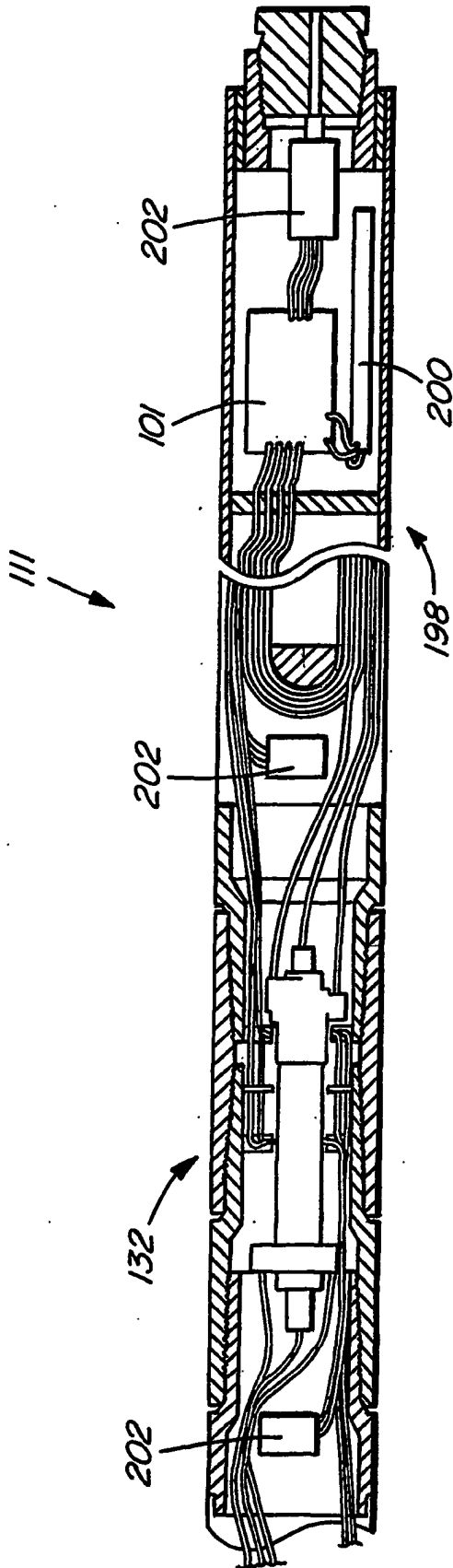


FIG. 19

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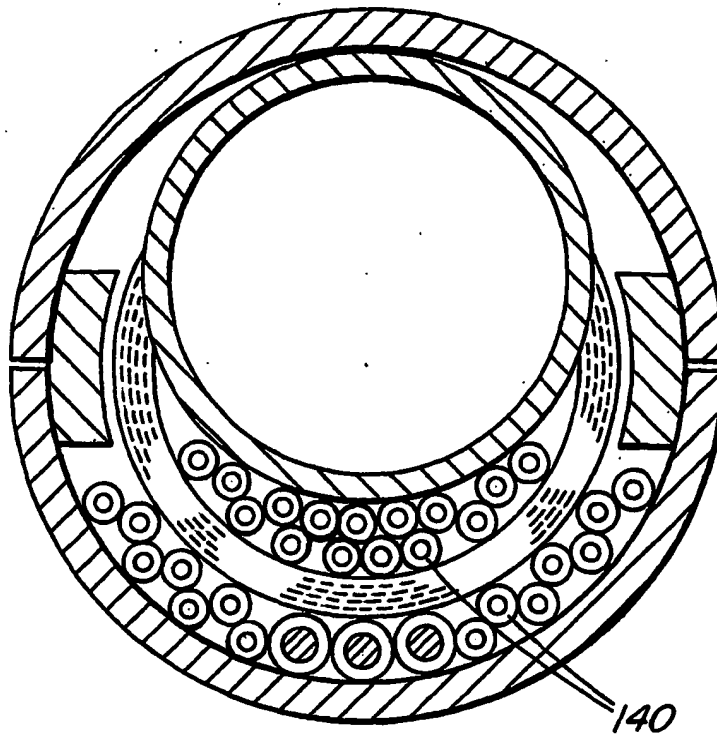


FIG. 20

## INTERNATIONAL SEARCH REPORT

International Application No

PCT/CA 01/00334

A. CLASSIFICATION OF SUBJECT MATTER  
IPC 7 E21B33/13 E21B36/00

According to International Patent Classification (IPC) or to both national classification and IPC

## B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)

IPC 7 E21B

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practical, search terms used)

EPO-Internal, PAJ, WPI Data, TULSA

## C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category *	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	US 2 363 269 A (M. SCHLUMBERGER) 21 November 1944 (1944-11-21) page 1, line 11 - line 22; figure 1 page 2, line 69 - line 72 ----	1,7
A	US 3 208 530 A (T.O. ALLEN) 28 September 1965 (1965-09-28) column 1, line 41 - line 55; figure 4 ----	1,7
A	US 4 024 916 A (HARTLEY JAMES N ET AL) 24 May 1977 (1977-05-24) column 2, line 4 - line 24; figure 1 ----	1,7
A	US 4 489 784 A (MESSENGER JOSEPH U) 25 December 1984 (1984-12-25) column 2, line 29 - line 58 ----- -/--	1,7



Further documents are listed in the continuation of box C.



Patent family members are listed in annex.

## \* Special categories of cited documents:

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Date of the actual completion of the international search

2 August 2001

Date of mailing of the international search report

09/08/2001

Name and mailing address of the ISA

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## INTERNATIONAL SEARCH REPORT

International Application No  
PCT/CA 01/00334

C.(Continuation) DOCUMENTS CONSIDERED TO BE RELEVANT		
Category °	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	GB 2 320 271 A (SCHLUMBERGER LTD) 17 June 1998 (1998-06-17) claim 1; figure 4 ----	1,7
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